Low Density Flexible Carbon Phenolic Ablators

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Background

State of the Art (SoA) Low Density Carbon Phenolic Ablators

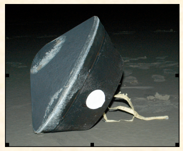


Image of the sample return capsule post flight with PICA as the forebody TPS.

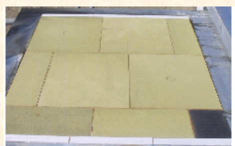
- Phenolic Impregnated Carbon Ablator (PICA) was an enabling TPS material for the Stardust mission where it was used as a single piece heatshield
- PICA has the advantages of low density (~0.27g/cm^3) coupled with efficient ablative capability at high heat fluxes
- More recently, PICA was chosen as the primary heatshield for Mars Science Lab (MSL) and Space-X's Dragon

Challenges with SoA Configurations

- Under the Orion program, PICA was shown to be capable of both ISS and lunar return missions; however some unresolved issues remain for its application in a tiled configuration for the Orion-specific design, including a brittle char and developing a suitable gap filler. In particular, the problem of developing an appropriate gap filler resulted in the Orion program selecting AVCOAT as the primary heatshield material over PICA.

Char Cracking in System Level Tile Array Tests

- Solar Tower testing on an array of PICA tiles with various gap filler materials induced high in-plane compressive stresses (caused by the high temperature gradients) in the samples.



Pre test PICA tile Array

- Articles survived the heating, however additional loads caused char cracking and failure in the char. For the image shown the additional loading caused some of char to fall off adjacent tiles. This highlights the challenges when designing with gap filler materials not compatible with PICA

Post test PICA tile Array

Developing Suitable Gap Filler Solutions for PICA

- Developing a suitable gap filler material that meets the thermal and structural requirements is not trivial
- Images to the right highlight the challenges with compatible gap filler materials. In the lower heat flux condition, fencing of the gap filler material is observed as it recedes slower than the PICA material, however in the higher test condition the gap filler material recedes faster leaving a gap

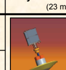
156 W/cm^2, 100 sec

643 W/cm^2, 70 sec

Flexible ablators are enabling for many future entry missions

Entry Vehicle Concept	Location	Diameter (m)	Q (W/cm^2) A/E	Margin q?	Pressure (k/Pa) A/E	Shear (Pa) A/E
EDL SA, ADEPT	Peak Forebody	23	106/32	Yes	11/8	42/25
EFF, direct entry	Peak Forebody	6	23	Yes	14	287
EFF, direct entry	Peak Forebody	8	171	Yes	10	207
ADEPT, Venus	Peak Forebody	2.13	230	No	7	210
ADEPT, Saturn	Peak Forebody	2.13	295	No	11	245

Adaptive Deployable Entry-system Project (ADEPT) (23 m diameter)



Exploration Feed Forward (EFF) Concepts (6, 8 m diameters)

ADEPT Concept (2.13 m diameter)

New Flexible Carbon Phenolic Development Effort at ARC

Flexible PICA is currently under development

- Material is comparable in composition to PICA
- Material remains flexible after charring
- Material can be processed as large pieces
- Parameters such as thickness, density etc are tailorable

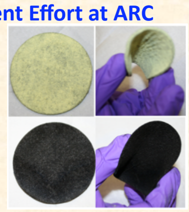


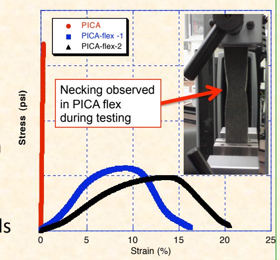
Image of flexible ablator (a) as processed and (b) after fully charring demonstrating the flexibility of the material in both the virgin and charred state

Results from Preliminary Screening Tests

Candidate systems have been processed and are currently going through a series of screening tests that include mechanical, thermal and relevant environment screening (arc jet, LHMEL, HyMETs)

Mechanical Testing

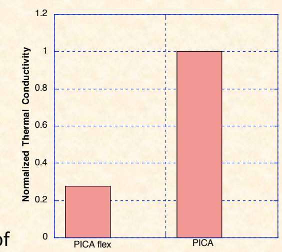
- Samples were tested in tension in the IP direction to evaluate strength and strain to failure. (8" x 1")
- PICA flex failed very gracefully during the test and showed necking behavior – a phenomenon that is traditionally present in very ductile materials.
- PICA flex was able to withstand about 8%-12% strain before onset of necking
- For comparison, a PICA stress strain curve is also provided - strain to failure of PICA is < 1% which leads to difficulties in designing with PICA
- While PICA has higher strength, in applications that are strain to failure driven, PICA flex has advantages



Stress strain data for PICA flex and PICA PICA is included. Insert - Image of necking observed in PICA flex

Room Temperature Thermal Conductivity

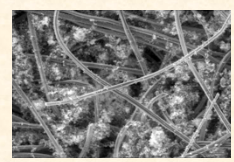
- The laser flash method was used to evaluate thermal conductivity in PICA flex
- Data presented is an average of 3 samples
- For comparison, the thermal conductivity of PICA are also provided
- For this test series the PICA and PICA flex samples have comparable densities, however, the thermal conductivity of PICA flex is approximately a third of that of rigid PICA



Normalized thermal conductivity for PICA flex and PICA materials

Microstructure

- Characterizing the microstructure of a TPS material is important as the constituent distribution at the microstructural level will influence properties
- PICA flex has a microstructure that resembles PICA in many aspects; distributed phenolic phase in a carbon matrix



Representative PICA flex microstructure

Arc Jet Exposure

- Initial arc jet screening has been completed at the Johnson Space Center arc jet facility
- Samples were 3" diameter by ~ 1" thick and bonded to an LI 2200 tile holder and were instrumented with a backface thermocouple
- Initial arc-jet tests show PICA flex performing well at 520 W/cm^2, 35 kPA
- Performance limits for flexible ablators have yet to be determined

Pre test

Post test

Summary

- We are currently looking at alternative architectures to yield flexible and more conformal carbon phenolic materials with comparable performance to PICA
- Flexible TPS concepts address some of the design issues faced in the application of a tiled PICA heat shield.
- Initial testing of flexible PICA concepts has been encouraging:
    - Substantially higher strain to failure than PICA
    - Lower thermal conductivity than PICA
    - Survived a 520 W/cm^2, 35 kPa arc jet exposure
- These new materials are enabling for upcoming NASA missions and as material candidates for private sector Commercial Orbital Transportation Services (COTS).

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